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PERFORMANCE OF RAFT & PILE FOUNDATION ON SOFT ARIAKE CLAY GROUND UNDER EMBANKMENT LOADING

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ABSTRACT: Road constructions are being planned along the Ariake Sea Gulf of Japan. This paper proposes a new foundation method for an embankment on soft subsoil by using high durability and non-polluting materials. Recently, the global warming is progressing. To address the problem of the global warming, using a lot of wood as construction material and making a forest active are one of the problems to be solved. Field investigation has shown that even after more than one thousand years, brush wood reinforcement under the Mizuki embankment in north Kyushu, Japan; still have high durability with under water table condition. In this study, a series of laboratory model tests and finite element analysis were carried out to investigate the effectiveness of Raft & Pile method for soft ground improvement for construction of highway embankments on soft Ariake clay. Results can be investigated that, embankment loading on the soft Ariake clay without any extra ground support large settlement and large deformation occur. With Raft & Pile settlement and deformation in soft ground was reduced significantly.

Keywords: Raft & pile foundation, embankment, natural-non polluting materials, FEM, deformation

INTRODUCTION

The construction of road embankments over soft subsoil such as Ariake clay will cause large settlement and lateral deformation. These deformations will be transferred to the surrounding ground and will cause the damage to the civil buildings and agricultural land along the highway (Hayashi et al., 1997). Therefore, the soft subsoil should be treated by various methods, such as basal reinforcement in the embankment (Chai et al., 2002), deep mixed columns (Shen and Miura, 2001), steel grid reinforced embankment (Bergado et al., 2007), etc. Most of the methods employ artificial geosynthetics and/or chemical admixtures for improvement. The use of the artificial material may cause environmental problems in a long-term.

This paper proposes a new method termed here as 'Raft & Pile foundation method' that uses the surplus trees from mountains as the foundation for the embankment. This method is aimed at reducing both settlement and lateral displacement of the surrounding land due to the embankment loading. Since the raft and piles are made of the surplus trees which are freely available except for the transportation cost, this is an economic method of construction. Also, the global warming is an important issue. The use of the surplus wood for construction makes the forest active and thus addresses the problem of the global warming (Numata and Uesugi, 2006). Field investigations have shown that even after more than one thousand years, wood reinforcement under the Mizuki embankment in north Kyushu, Japan still has high durability in an under water-table condition (Hayashi and Du, 2005). Therefore, the proposed method is expected to be a sustainable method. This study investigates the effectiveness of the Raft and Pile foundation through laboratory model tests and numerical simulations.

ANALYSIS OF LABORATORY TEST RESULTS

Ariake clay in slurry condition is filled in the model box test to initial depth. An overburden pressure of about 2.8 kPa is applied over 5 weeks under drained condition at the surface and bottom of the tank. The model of Raft & Pile foundation is then installed beneath the position of the embankment. The embankment load is applied corresponding to multi stage of embankment

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Note: Discussion on this paper is open until December 2010

Table 1 Material properties

		Laboratory test(1)			Field conditions(2)					
		Ariake clay (Kawazoe) 0m-0.3m	Sand	timber	Weathered crust (B) 0m-1m	Ariake clay (Ac2) 1m-11m	Sand (As2) 11m-16m	Dense Sand (Ds) 16m-30m	Fill	timber
Model type		*Soft Soil*	*Mohr Coulomb*	*Linear Elastic*	*Soft Soil*	*Soft Soil*	*Linear Elastic*	*Linear Elastic*	*Mohr Coulomb*	*Linear Elastic*
γ_{unsat}	[kN/m³]	15.20	17	4.70	15.0	14.50	15.50	19.00	16.0	4.70
k_x	[m/day]	0.00056	1	-	0.00989	0.00228	0.25056	0.25056	1	-
k_y	[m/day]	0.00056	1	-	0.00657	0.00152	0.25056	0.25056	1	-
λ^*	[-]	0.26	-	-	0.083	0.25	-	-	-	-
κ^*	[-]	0.026	-	-	0.0083	0.025	-	-	-	-
e_{init}	[-]	2.0	1	-	2.0	2.5	1	1	1	-
E_{ref}	[kN/m²]	-	4.0E04	1.0E08	-	-	1.5E04	3.0E04	8.0E03	1.0E08
ν	[-]	0.3	0.30	0.33	0.25	0.3	0.20	0.20	0.30	0.33
c	[kN/m²]	4.6	1	-	5	5	-	-	1	-
φ	[°]	17.0	30	-	25	25	-	-	30	-
OCR	[-]	1	-	-	4	1.2	-	-	-	-

Note: (1) Parameter was determined from laboratory test, except for Sand (Plaxis) and timber (WWW.hcitasca.com)

(2) Chai et al 1999, except for Fill (Plaxis) and timber (WWW.hcitasca.com)

Table 2 Test cases

	Laboratory test				Field test (embankment height7.5m)	
Foundation type	Without Raft & Pile (MT-0)	With Raft (MT-R1)	With Raft & Pile (MT-RP1)	With Raft & Pile (MT-RP2)	Without Raft & Pile	With Raft & Pile (2R6P)
Dimension of rafts	-	Square shape 0.005m*0.005m	Square shape 0.005m*0.005m	Square shape 0.005m*0.005m	-	Circle shape diameter 0.2m
Thickness of raft	-	0.005m	0.005m	0.005m	-	0.37m
Spacing	-	-	-	-	-	-
Width of rafts	-	0.36m	0.20m	0.20m	-	32m
No. of layer raft	-	1	1	1	-	2
Dimension of piles	-	-	Square shape 0.005m*0.005m	Square shape 0.005m*0.005m	-	Circle shape diameter 0.2m
Spacing	-	-	0.005m	0.005m	-	-
Installed depth of piles	-	-	0.07m	0.10m	-	6m

constructions in field. The details of the laboratory tests have been reported by Poungchompu et al. (2008).

In the finite-element analysis, the plane strain condition was assumed. The model was 30 cm deep from the ground surface and 90 cm wide. The displacement boundary conditions were as follows: at bottom, both vertical and horizontal displacements were fixed; and for left and right vertical boundaries, the horizontal displacement was fixed. Figure 1 shows the finite element mesh for the analyses of model test; the loading pattern is also indicated in Fig. 1. The mechanical behavior of the clay layers was represented by a

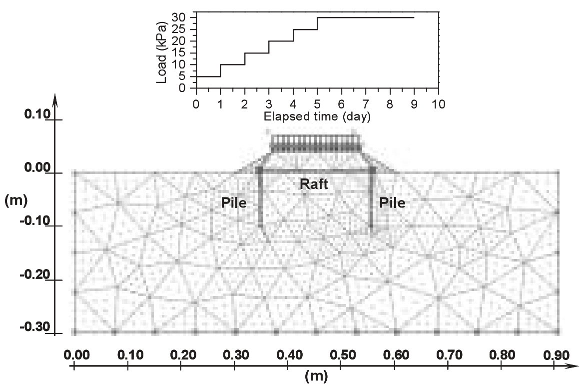
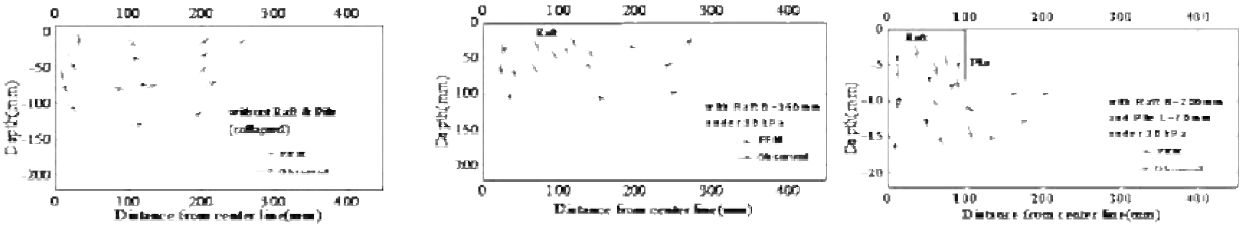
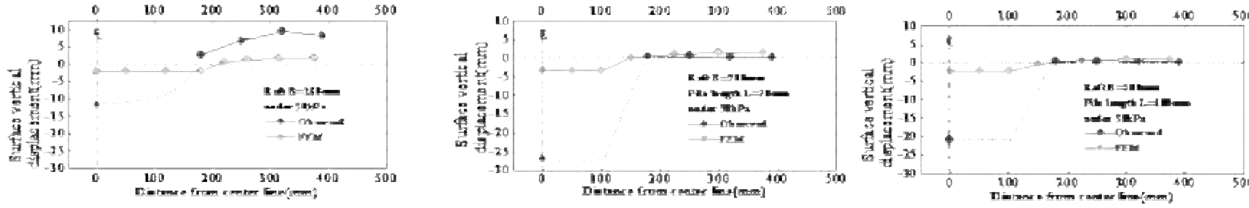


Fig. 1 Typical finite-element mesh for laboratory test



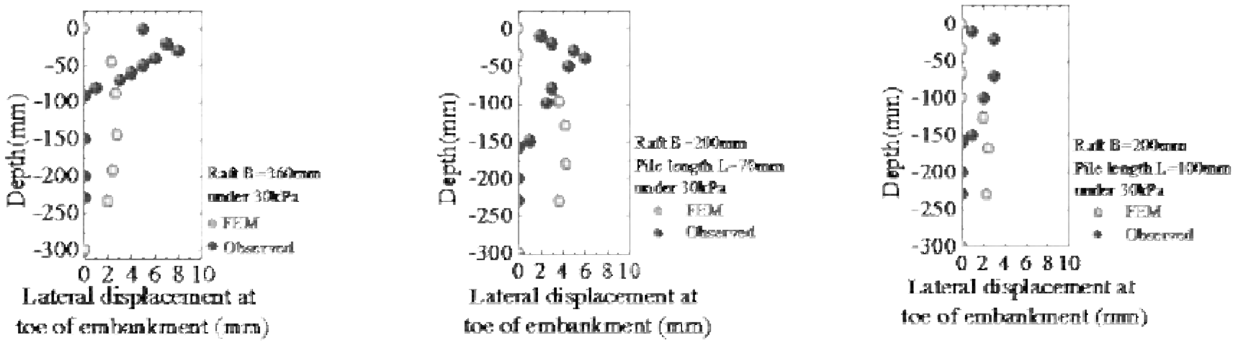
(a) (b) (c)

Fig. 2 Displacement in the ground (a) case without Raft & Pile, MT-0 (b) case with Raft, MT-R1 (c) case with Raft & Pile, MT-RP1.



(a) (b) (c)

Fig. 3 Surface vertical displacement (a) case with Raft, MT-R1 (b) case with Raft & Pile, MT-RP1 (c) case with Raft & Pile, MT-RP2.



(a) (b) (c)

Fig. 4 Lateral displacement at section of toe embankment (a) case with Raft , MT-R1 (b) case with Raft & Pile, MT-RP1 (c) case with Raft & Pile, MT-RP2.

soft soil model and the sand mat layers were assumed to be elastic. The model parameters for the subsoil as determined from the experiments are listed in Table 1. Timber for Raft & Pile foundations was assumed to be elastic (www.hcitasca.com). The ground-water table was assumed to be at the ground surface. The conditions of the four model tests, namely, MT-0F (without Raft & Pile foundation), MT-R1 (only with a raft of 360 mm width), MT-RP1 (with a raft width of 200 mm and pile length of 70 mm) and MT-RP2 (with a raft width of 200 mm and pile length of 100 mm) are summarized in Table2.

The measured displacement vectors, surface vertical displacement and lateral displacement at the end of tests are compared with the finite element analyses in Figs. 2, 3 and 4, respectively. Figure 2 shows that the observed data for displacement vectors are comparable to that of the finite element analysis. Figure 2(a) shows that for the case without raft and pile, a large amount of vectors move outwards and upwards toward the free ground surface. For the case with only raft support (Fig. 2b), displacement vectors generally move downwards to deeper subsoil; but near the toe of the embankment, some vectors also move outwards. Figure 2(c) shows that for the case of Raft and Pile foundation, the displacement vectors are directed downwards and the displacement is restricted within the confined soil mass between the piles.

In general, the predicted displacements by the finite element analyses are less than the observed values (Figs. 3 and 4). The finite element method has a central requirement that the field quantities (stress, displacement) vary throughout each element in a prescribed fashion, using specific function controlled by parameters. The formulation involves the adjustment of these parameters to minimize error terms or energy term (Theory & Background FLAC4.0).

For the case with raft support only (MT-R1), while the observed maximum surface displacement at the center is around 11 mm and the maximum heave beyond the toe is around 10 mm, the corresponding displacements predicted by the finite element analysis are 2.2 mm and 1.7 mm, respectively (Fig. 3a). For the Raft and Pile foundation (MT-RP1), the maximum observed vertical displacement at the center is approximately 27 mm and beyond the toe, the maximum heave is approximately zero (Fig. 3b). The corresponding displacements predicted by the finite element analysis are 3.3 mm and 1.5 mm, respectively. For another case of Raft and Pile foundation (MT-RP2), Fig. 3(c) shows that while the observed displacement at the center reduces to 21 mm and the heave beyond the toe remains zero, the corresponding displacements predicted by the finite element analysis are 2.2 mm and 1.1 mm, respectively.

Figure 4(a) shows that for the case MT-R1, while the maximum lateral displacement is 8 mm at a depth of 40 mm and reduces to zero at 100 mm depth, the maximum lateral displacement predicted by the finite element analysis is 3 mm at 120 mm depth and decreases to zero at 250 mm depth. The observed maximum lateral displacement for MT-RP1 case is 6 mm at 50 mm depth and zero at 150 mm depth (Fig. 4b). The corresponding predictions are 5 mm at 150 mm depth and zero at 250 mm depth. For MT-RP2 case (Fig. 4c), while the maximum observed lateral displacement is 4 mm at 30 mm depth and zero at 150 mm depth, the corresponding finite element predictions are 3 mm at 180 mm depth and zero at 250 mm depth.

PERFORMANCE OF A ROAD EMBANKMENT OF HEIGHT 7.3 M WITH AND WITHOUT RAFT & PILE FOUNDATION ON SOFT GROUND

In the finite-element analysis, the plane strain condition was assumed. The discretized model was 30 m deep from the ground surface, and 80 m wide from the embankment center line (Fig. 5). The displacement boundary conditions were as follows: at bottom, both vertical and horizontal displacements were fixed; and for left and right vertical boundaries, the horizontal displacement was fixed. The adopted drainage boundary conditions were as follows: the ground surface and the bottom surface (sand layer) were drained; the left and right boundaries were also drained. Figure 5 shows the finite element mesh for the cross section of embankment used here (Fig. 6). The construction history is also indicated in Fig. 5. The mechanical behaviour of the clay layers is represented by the soft soil model and the sand layers were assumed to be elastic. The model parameters used for the subsoil (Chai et al., 1999) and other materials are listed in Table 2. The timber for Raft & Pile foundation was assumed to be elastic (www.hcitasca.com). The ground water table was assumed at the ground surface. The mechanical property of the fill material was represented by the Mohr-Coulomb model (Plaxis V.8). The conditions of the two field tests are summarized in Table 1.

Figure 7 presents the settlement at the embankment center with the elapsed time. The effectiveness of Raft and Pile foundation is evident from the figure. While the maximum vertical settlement of the embankment is approximately 2.9 m after 3 years, the corresponding

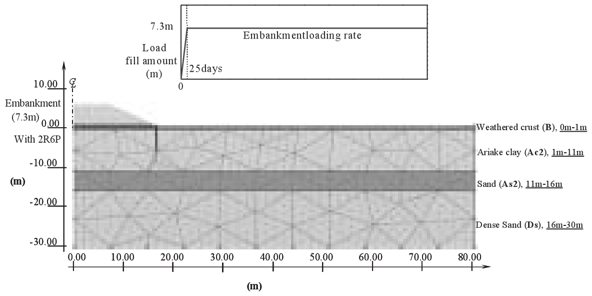


Fig. 5 Typical finite-element mesh for field test

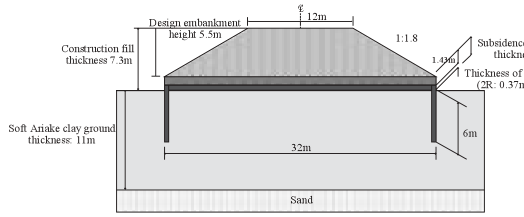


Fig. 6 Cross section of embankment

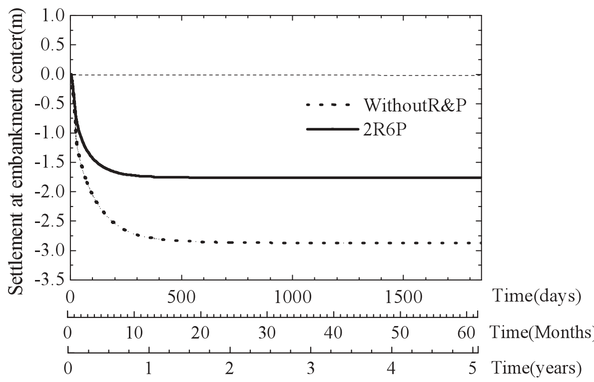
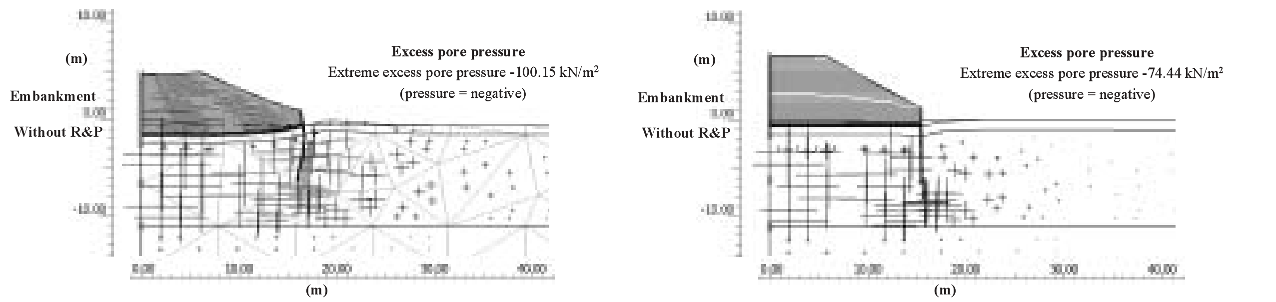
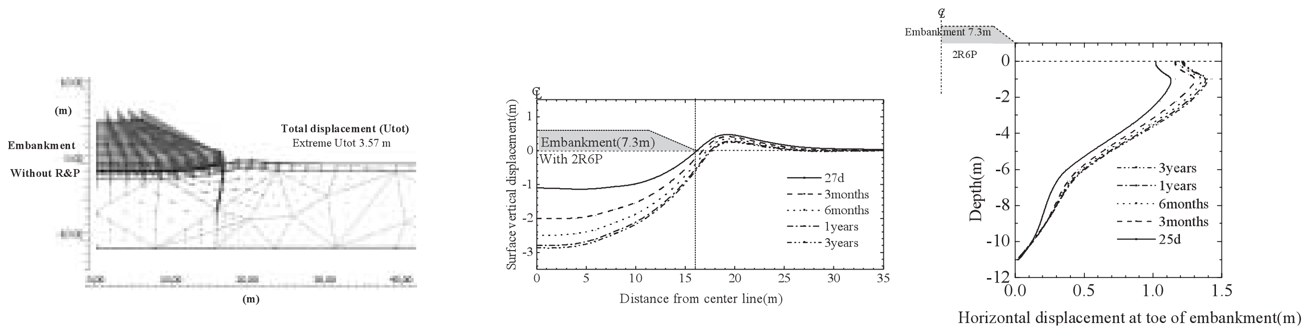


Fig. 7 Settlement at embankment center



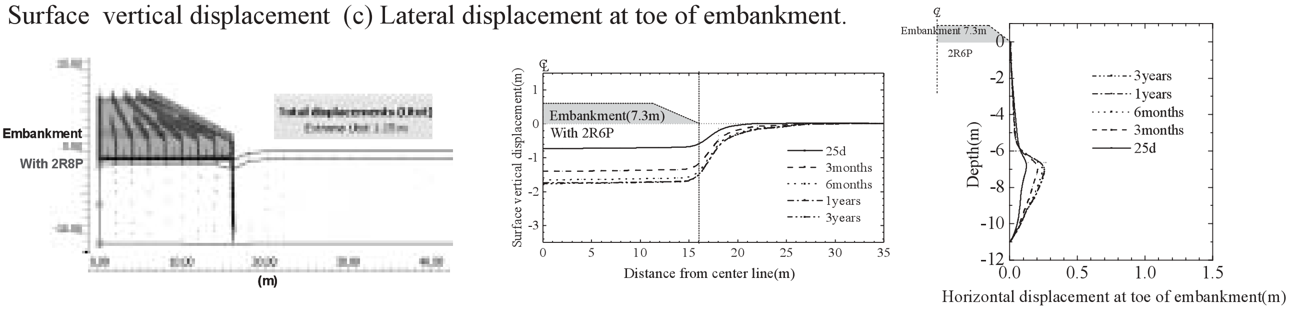
(a) (b)

Fig. 8 Excess pore pressures distribution after undrained construction of embankment (a) case without Raft & Pile (b) case with Raft & Pile



(a) (b) (c)

Fig. 9 Displacement for case without Raft & Pile (a) Total displacement after end of construction (25days) (b) Surface vertical displacement (c) Lateral displacement at toe of embankment.



(a) (b) (c)

Fig. 10 Displacement for case with Raft & Pile (a) Total displacement after end of construction (25days) (b) Surface vertical displacement (c) Lateral displacement at toe of embankment.

settlement is only about 1.8 m if Raft and Pile foundation is used.

Figure 8 shows the excess pore water pressure distribution below the deformed shape of the embankment. The maximum excess pore water pressure is 100.15 kPa for the case without raft and pile. The corresponding value for the case with raft and pile is 74.44 kPa.

Figure 9(a) shows the total displacement vectors at the end of the construction for the case without Raft and Pile foundation.

The deformed mesh shows the uplift of the embankment toe and hinterland. On evaluation of the total displacement increments, it can be seen that the failure mechanism is developing (Fig. 9a). Figure 9(b) shows that the maximum surface displacement at the center of the embankment is about 2.9 m after 3 years. Beyond the toe, a heave of about 0.27 m is noticed which slowly reduces to zero at a distance of about 35 m from the centerline. Figure 9 (c) shows that the maximum lateral displacement of about 1.43 m occurs at the toe of the embankment at 1 m depth. The lateral displacement at the toe steadily decreases to zero at a depth of 11 m.

For the case of the embankment with Raft and Pile foundation, the displacement vectors are generally downward directed and remain confined within the pile length (Fig. 10a). Figure 10(b) shows that the surface heaves beyond the toe is negligible and the maximum settlement at the centerline reduces significantly (in order of 3/5 times as compared to the case without Raft and Pile foundation). This brings out the clear advantage of Raft and Pile foundation. The lateral displacement beneath the toe of the embankment increases with depth and reaches the maximum of 0.27 m at a depth of 6.7 m (Fig 10c). It then decreases to zero at approximately 11 m depth. Thus, Raft and Pile foundation also reduces the lateral displacement effectively.

Based on the results mentioned above, for a 12 m wide and 5.5 m high embankment with 1V: 1.8 H slope constructed on soft Ariake clay bed of 11 m thickness, the probable dimension of Raft and Pile foundation is as follows (Fig. 6): Raft in two layers of timber of total thickness 0.37 m and width 32 m; piles of diameter 0.2 m and length 6 m; and subsidence correction thickness of 1.8 m.

CONCLUSIONS

Based on the model test results and the finite element analysis, the following conclusions are drawn:

Without adequate foundation support, the embankment loading (Fig. 6) on soft Ariake clay deposits causes large vertical settlements and lateral movements.

If Raft and Pile foundation is used to support the embankment, the vertical settlement of the embankment reduces significantly and the lateral movement of the embankment toe becomes negligible.

FEM analysis has shown that timber Raft & Pile also reduce and the generation of excess pore pressures in the subsoil and its rate of dissipation.

For a 12 m wide and 5.5 m high embankment with 1V: 1.8 H slope built on soft Ariake clay bed of 11 m thickness, the probable Raft and Pile foundation dimensions are: Raft in two layers of total thickness 0.37 m and width 32 m; piles of diameter 0.2 m and length 6 m; and subsidence correction thickness of 1.8 m.

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